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SPECIFICATION <EXCERPT>

[0010]

As described above, CMOS sensors have been used in portable apparatuses, with their characteristics of smaller sizes and lower power consumption. On the other hand, they have a serious problem of degradation of images due to hand-shake, in cases of portable image inputting apparatuses.

[0011]

For example, with reference to Fig. 7(a), in cases where a rectangular object is photographed with an image inputting apparatus, if the image inputting apparatus is at rest and no hand-shake occurs, no abnormality will occur in a captured image.

[0012]

On the contrary, if the image inputting apparatus is shaken by hand in the leftward direction, with reference to Fig. 7(b), and if the image inputting apparatus is shaken by hand in the rightward direction, with reference to Fig. 7(c), large distortions will occur in the captured image.

[0013]

With reference to Fig. 7(d), if the image inputting apparatus is shaken by hand in the upward direction, the object is photographed in a vertically-enlarged manner. Further, with reference to Fig. 7(e), if the image inputting apparatus is shaken by hand in the downward direction, the object is photographed in a vertically-contracted manner.

[0014]

Particularly, image distortions caused by rightward and leftward hand-shakes will significantly change the captured shape of the object, and therefore, will be significantly visually obtrusive to cause image degradations.

[0015]

Accordingly, there is necessarily a need for a countermeasure against these phenomena. As such a countermeasure, there has been suggested in JP-A No. 9-181986, a method for rapidly reading out images from a solid image pickup device within a time interval smaller than a single-frame time interval. However, this method increases the clock frequency required for readout, thereby causing the problem of an increase of power consumption.

[0016]

The present invention is made in view of the aforementioned circumstances and aims at providing an image inputting apparatus capable of correcting image distortions caused by hand-shakes without increasing power consumption, in cases of using an X-Y address type solid image pickup device.

[0017]

[Means for Solving the Problem]

An image inputting apparatus according to an aspect of the present invention includes a solid image pickup device having an area sensor portion including photoelectric conversion devices arranged on a two-dimensional plane defined by predetermined first and second directions, a first scanning portion which is connected to the area sensor portion and selects in order in the first direction the respective lines of the photoelectric conversion devices in the second direction in the area sensor portion on a line-by-line basis and a second scanning portion which is connected to the area sensor portion and selects in order in the second direction image-pickup signals output from the photoelectric conversion devices along the lines; a hand-shake detecting portion for detecting hand-shake generated during photographing and outputting hand-shake information according to the direction and the amount of the hand-shake; a hand-shake correction value calculating portion which is connected to the hand-shake detecting portion and calculates the amount of movement of the solid image pickup device in the second direction, on the basis of the hand-shake information output from the hand-shake detecting portion; and a timing generating portion which is connected to the hand-shake correction value calculating portion and the solid image pickup device and controls to change the pixel selection starting position for the second scanning portion, on the basis of the amount of movement in the second direction and the line position selected by the first scanning portion.

[0018]

The timing generating portion changes the pixel selection starting position for the second scanning portion, on the basis of the amount of movement in the second direction and the line position selected by the first scanning portion. This enables correcting the image distortions caused by the hand-shakes in the second direction. Further, image-pickup signals can be read out from the solid image pickup device using a conventional clock frequency, thereby preventing increase of power consumption.

[0019]

Preferably, the hand-shake correction value calculating portion includes a first-direction hand-shake correction value calculating means for calculating the amount of movement of the solid image pickup device in the first direction, on the basis of the hand-shake information output from the hand-shake correction portion and a second-direction hand-shake correction value calculating means for calculating the amount of movement of the solid image pickup device in the second direction, on the basis of the hand-shake information output from the hand-shake correction portion. The image inputting apparatus further includes an image storage portion which is connected to the solid image pickup device and stores image-pickup signals read out from the solid image pickup device, corresponding to at least a single screen; and an image storage control portion which is connected to the first-direction hand-shake correction value calculating means and the image storage portion and controls the readout in the first direction of image pickup signals stored in the image storage portion, on the basis of the amount of movement in the first direction.

[0020]

The image storage control portion controls the readout in the first direction of image pickup signals stored in the image storage portion, on the basis of the amount of movement in the first direction. This enables correcting the image distortions caused by hand-shakes in the first direction.

[0021]

An image inputting apparatus according to another aspect of the present invention includes a solid image pickup device having an area sensor portion including photoelectric conversion devices arranged on a two-dimensional plane defined by predetermined first and second directions, a first scanning portion which is connected to the area sensor portion and selects in order in the first direction the respective lines of the photoelectric conversion devices in the second direction in the area sensor portion on a line-by-line basis, and a second scanning portion which is connected to the area sensor portion and selects in order in the second direction image-pickup signals output from the photoelectric conversion devices along the lines; an image storage portion which is connected to the solid image pickup device and stores image pickup signals read out from the solid image pickup device, corresponding to at least a single screen; a hand-shake detecting portion for detecting hand-shake generated during photographing and outputting hand-shake information according to the direction and the amount of the hand-shake; a hand-shake correction value calculating portion which is connected to the hand-shake detecting portion and calculates the amount of movement of the solid image pickup device in the second direction, on the basis of the hand-shake information output from the hand-shake detecting portion; and an image storage control portion which is connected to the hand-shake correction value calculating portion and the image storage portion and controls the readout in the second direction of image-pickup signals stored in the image storage portion, on the basis of the amount of movement in the second direction.

[0022]

The image storage control portion controls the readout in the second direction of image pickup signals stored in the image storage portion, on the basis of the amount of movement in the second direction. This enables correcting the image distortions caused by hand-shakes in the second direction. Further, image pickup signals can be read out from the solid image pickup device using a conventional clock frequency, thereby preventing increase of power consumption.

[0023]

Preferably, the hand-shake correction value calculating portion includes a first-direction hand-shake correction value calculating means for calculating the amount of movement of the solid image pickup device in the first direction on the basis of the hand-shake information output from the hand-shake correction portion, and a second-direction hand-shake correction value calculating means for calculating the amount of movement of the solid image pickup device in the second direction, on the basis of the hand-shake information output from the hand-shake correction portion. The image storage control portion includes a first-direction image storage control means which is connected to the first-direction hand-shake correction value calculating means and the image storage portion and controls the readout in the first direction of image pickup signals stored in the image storage portion, on the basis of the amount of movement in the first direction, and a second-direction image storage control means which is connected to the second-direction hand-shake correction value calculating means and the image storage portion and controls the readout in the second direction of image pickup signals stored in the image storage portion, on the basis of the amount of movement in the second direction.

[0024]

The image storage control portion controls the readout of image pickup signals stored in the image storage portion in the first direction, on the basis of the amount of movement in the first direction. This enables correcting the image distortions caused by hand-shakes in the first direction.

[0025]

[Mode for Carrying out the Invention]

[First Embodiment]

With reference to Fig. 1, an image inputting apparatus according to a first embodiment includes an X-Y address type solid image pickup device 1 for converting optical images of an object into electrical signals, a pre-processing portion 2 which is connected to the solid image pickup device 1 and performs pre-processing such as CDS (Correlated Double Sampling), AGC (Automatic Gain Control) and ADC (Analog to Digital Convert: A/D conversion) on the outputs from the solid image pickup device 1 to convert them into digital signals, a signal processing portion 3 which is connected to the pre-processing portion 2 and divides the digital signals resulted from the conversion by the pre-processing portion 2 into brightness signals and color signals, then performs white-balancing processing, gamma correction and the like on the aforementioned signals and converts the aforementioned signals into image signals of a proper format (for example, YUV, RGB), and an I/F (Interface) portion 5 for use in inputting and outputting data to and from personal computers and the like.

[0026]

The image inputting apparatus further includes an image storage portion 4 which is connected to the signal processing portion 3 and the I/F portion 5 and temporality stores image data, in cases where the image data is to be subjected to JPEG (Joint Photographic Experts Group) compression or MPEG (Moving Picture Experts Group) compression, in order to perform buffering of image signals for changing the speed in cases where the transfer speed of image signals output from the signal processing portion 3 is not equal to the processing speed of the I/F portion 5, or in order to reduce the amount of data transferred through the I/F portion 5. Further, the image inputting apparatus includes a timing generating portion 6 which is connected to the solid image pickup device 1 and the pre-processing portion 2 and generates various types of pulses for driving the solid image pickup device 1 and pulses required by the pre-processing portion 2, and an image storage control portion 7 which is connected to the image storage portion 4 and controls the writing and the reading of data into and from the image storage portion 4.

[0027]

The image inputting apparatus further includes a hand-shake detecting portion 8 constituted by an angular-velocity sensor or the like mounted near the solid image pickup device 1, wherein the hand-shake detecting portion 8 detects hand-shake caused by a user during photographing and outputs hand-shake information according to the direction and the amount of the hand-shake. Also, the image inputting apparatus further includes a hand-shake correction value calculating portion 9 which is connected to the timing generating portion 6 and the hand-shake detecting portion 8, wherein the hand-shake correction value calculating portion 9 calculates correction data for correcting the movement due to the hand-shake, on the basis of the hand-shake information output from the hand-shake detecting portion 8, on a pixel-by-pixel basis, and supplies the correction data to the timing generating portion 6.

[0028]

The I/F portion 5 is constituted by, for example, a PCI (Peripheral Component Interconnect) bus, a PC card, an USB (Universal Serial Bus), an IEEE (Institute of Electrical and Electronics Engineers) 1394 and the like.

[0029]

The hand-shake detecting portion 8 is not limited to an angular-velocity sensor. The solid image pickup device 1 includes an area sensor 11 including photoelectric conversion devices arranged in a two-dimensional shape, a vertical scanning portion 12 which is connected to the area sensor portion 11 and successively selects in the vertical direction the horizontal lines of the photoelectric conversion devices in the area sensor portion 11 on a line-by-line basis, a horizontal scanning portion 13 which is connected to the area sensor portion 11 and successively selects in the horizontal direction image signals output from the photoelectric conversion devices along the aforementioned lines, and an output circuit portion 4 for converting the pixel signals from the photoelectric conversion devices selected by the vertical scanning portion 12 and the horizontal scanning portion 13 into voltages and outputs the voltages.

[0030]

With reference to Fig. 2, the pixel structure of the area sensor portion 11 will be described. In this case, the number of the effective vertical lines of image signals output from the area sensor portion 1 is defined as N, and the number of the effective horizontal pixels is defined as M. The hand-shake correction value calculation portion 9 calculates the amount of hand-shake generated between the first-selected line (j=1) and the last-selected line (j=N) in the area sensor portion 11, from the horizontal hand-shake information detected by the hand-shake detecting portion 8, and outputs, to the timing generating portion 6, the amount of hand-shake as correction data for correcting the movement due to the hand-shake. For example, the hand-shake correction value calculating portion 9 determines, from calculation, the occurrence of leftward hand-shake corresponding to a pixels and outputs to the timing generating portion 6 correction data a for correcting the movement due to the hand-shake.

[0031]

With reference to Fig. 3, there will be described hand-shake correction processing in the timing generating portion 6.

[0032]

The timing generating portion 6 receives the horizontal correction data a from the hand-shake correction value calculating portion 9 and initializes a vertical line counter (j=1) (step S1). The timing generating portion 6 determines whether or not the horizontal correction data a is negative (step S2). If the correction data a is positive, leftward hand-shake has occurred. If it is negative, rightward hand-shake has occurred.

[0033]

In cases where the horizontal correction data a is positive or 0 (leftward hand-shake or no hand-shake has occurred: the step S2 results in No), an evaluation value x for use in determining the horizontal-pixel selection starting position is calculated on the basis of the following equation (1) (step S3).

[0034]

$X = a * j/N$ ...(1)

Here, in cases where no hand-shake has occurred, the horizontal correction data a is 0, and therefore, the horizontal-pixel selection starting position is not changed.

[0035]

In cases where the horizontal correction data a is negative (rightward hand-shake has occurred: the step S2 results in Yes), the evaluation value x for use in determining the horizontal-pixel selection starting position is calculated on the basis of the following equation (2) (step S4).

[0036]

$$X= a * j/N - a \quad \ldots(2)$$

In cases where the solid image pickup device 1 is a monochrome sensor (the step S5 results in Yes), in order to perform interpolation with a pixel closest to the pixel specified by the evaluation value x, the evaluation value x is rounded off to an integer value, and the rounded evaluation value x is substituted into the horizontal-pixel selection starting position p (step S6).

[0037]

In cases where the solid image pickup device 1 is a color sensor (the step S5 results in No), the area sensor portion 11 includes a color filter, and therefore, it is necessary to change the selection starting position p depending on the filter arrangement. In this case, it is assumed that the color filter having colors repeatedly arranged on two-pixel by two-pixel basis in the horizontal and vertical directions, is used.

[0038]

The evaluation value x is divided by 2, then the divided evaluation value x is rounded off to an integer value, then the rounded value is doubled, and the doubled value is substituted into the horizontal-pixel selection starting position p (step S7). As a result, the selection starting position p is an even number, which ensures that the order of colors output from the solid image pickup device 1 is not changed by executing the following processing. This enables correctly performing color processing with the signal processing portion 3.

[0039]

Next, a horizontal pixel counter is initialized (i=1) (step S8). Then, the (i+p)-th pixel on the j-th line is selected (step S9). Further, the horizontal pixel counter i is incremented one by one (step S10), and the processes at the steps S9 and S10 are repeated until the number of output pixel data reaches (M-|a|) (step S11).

[0040]

Further, the vertical line counter j is incremented one by one (step S12), and the processes at the steps S2 to S12 are repeated for all the effective vertical lines (step S13).

[0041]

As described above, the timing generating portion 6 controls to change the pixel selection starting position for the horizontal scanning portion 13, on the basis of the output from the hand-shake correction value calculating portion 9 and the position of the line selected by the vertical scanning portion 12. This enables correcting the image distortions caused by the horizontal hand-shake.

[0042]

Although the present processing reduces the number of effective horizontal pixels output from the solid image pickup device 1 from M to (M-|a|), it is possible to overcome the problem by utilizing, as the solid image pickup device 1, a solid image pickup device with a number of pixels greater than that of a required output screen size.

[Second Embodiment]

With reference to Fig. 4, an image inputting apparatus according to a second embodiment will be described. The image inputting apparatus according to the present embodiment employs a timing generating portion 26, instead of the timing generating portion 6, and also employs an image storage control portion 27, instead of the image storage control portion 7, in the hardware structure of the image inputting apparatus according to the first embodiment described with reference to Fig. 1. In the image inputting apparatus according to the first embodiment, the hand-shake correction value calculating portion 9 detects on a pixel-by-pixel basis the amount of movement, on the basis of hand-shake information supplied from the hand-shake detecting portion 8, and outputs to the timing generating portion 9 correction data for correcting the movement due to the hand-shake. However, in the present embodiment, the hand-shake correction value calculating portion 9 outputs correction data to the image storage control portion 27. The image storage control portion 27 controls the readout in the horizontal direction from the image storage portion 4 on the basis of the supplied correction data.

[0043]

The other hardware structure is the same as that of the first embodiment. Therefore, detailed description thereof is not provided herein.

[0044]

With reference to Fig. 5, there will be described hand-shake correction processing by the image storage control portion 27.

[0045]

The image storage control portion 27 receives horizontal correction data a from the hand-shake correction value calculating portion 9 and initializes a vertical line counter (j=1) (step S21). The image storage control portion 27 determines whether or not the horizontal correction data a is negative (step S22). If the correction data a is positive, leftward hand-shake has occurred. If it is negative, rightward hand-shake has occurred.

[0046]

In cases where the horizontal correction data a is positive or 0 (leftward hand-shake or no hand-shake has occurred: the step

S22 results in No), an evaluation value x for use in determining the horizontal-pixel readout starting position is calculated on the basis of the aforementioned equation (1) (step S23).

[0047]

In cases where the horizontal correction data a is negative (rightward hand-shake has occurred: the step S22 results in Yes), the evaluation value x for use in determining the horizontal-pixel readout starting position is calculated on the basis of the aforementioned equation (2) (step S24).

[0048]

The evaluation value x is rounded off to an integer value, and the rounded evaluation value x is substituted into the horizontal-pixel readout starting position p (step S26).

[0049]

Next, a horizontal pixel counter is initialized (i=1) (step S28). Then, the (i+p)-th pixel on the j-th line is read out (step S29). Further, the vertical pixel counter i is incremented one by one (step S30), and the processes at the steps S29 and S30 are repeated until the number of output pixel data reaches (M-|a|) (step S31).

[0050]

Further, the vertical line counter j is incremented one by one (step S32), and the processes at the steps S22 to S32 are repeated for all the effective vertical lines (step S33).

[0051]

As described above, the image storage control portion 27 controls to change the horizontal pixel readout position, on the basis of the output from the hand-shake correction value calculating portion 9 and the position of the vertical line. This enables correcting the image distortions caused by the horizontal hand-shake.

[0052]

In the present embodiment, in order to simplify the processing, the interpolation is performed with the pixel data of a pixel closest to the original position of the pixel, in reading out image data from the image storage portion 4. However, the present invention is not limited to the interpolation method, and the interpolation of pixel data may be performed using a linear interpolation method or a multinomial function.

[Third Embodiment]

In the aforementioned first and second embodiments, only horizontal hand-shake information detected by the hand-shake detecting portion 8 is employed for correcting image distortions caused by horizontal hand-shake.

[0053]

In the present embodiment, there will be described a method for correcting image distortions caused by vertical hand-shake, using vertical hand-shake information detected by the hand-shake detecting portion 8.

[0054]

The image inputting apparatus according to the present embodiment has the same hardware structure as that of the image inputting apparatus according to the second embodiment described with reference to Fig. 4. However, the hand-shake correction value calculating portion 9 and the image storage control portion 27 according to the present embodiment execute processes which are partially different from those of the second embodiment, in order to address vertical hand–shake as well. The other hardware structure is the same as that of the second embodiment. Therefore, detailed description thereof is not provided herein.

[0055]

The hand-shake correction value calculating portion 9 calculates the amount of horizontal hand-shake generated between the first-selected line (j=1) and the last-selected line (j=N) in the area sensor portion 11, from the horizontal hand-shake information detected by the hand-shake detecting portion 8. Further, the hand-shake correction value calculating portion 9 calculates the amount of vertical hand-shake, from the vertical hand-shake information detected by the hand-shake detecting portion 8. The hand-shake correction value calculating portion 9 outputs, to the image storage control portion 27, these amounts of hand-shakes as correction data for correcting the movement due to the hand-shakes. For example, the hand-shake correction value calculating portion 9 determines, from calculation, the occurrence of leftward hand-shake corresponding to a pixels and the occurrence of upward hand-shake corresponding to b lines and outputs, to the image storage control portion 27, horizontal correction data a and vertical correction data b for correcting the movement due to the hand-shakes.

[0056]

Accordingly, the image storage control portion 27 controls the vertical and horizontal readout from the image storage portion 4.

[0057]

With reference to Fig. 6, there will be described hand-shake correction processing by the image storage control portion 27.

[0058]

The image storage control portion 27 receives the horizontal correction data a and the vertical correction data b, from the hand-shake correction value calculating portion 9, and initializes a vertical line counter (j=1) (step S34).

[0059]

The image storage control portion 27 calculates an evaluation value y for use in determining the vertical line to be read out, on the basis of the following equation (3).

[0060]

$y = (N + b) * j/N$ ...(3)

Next, in order to perform interpolation with the pixel data on the line position resulted from hand-shake correction and a line closest to the line, the evaluation value y is rounded off to an integer value, and the rounded evaluation value y is substituted into the vertical readout line q (step S35).

[0061]

If the vertical readout line q exceeds the number of the effective lines N (the step S36 results in Yes), the readout of data from the image storage portion 4 ends. If the vertical readout line q is equal to or less than the number of the effective lines N (the step S36 results in No), the image distortions caused by the horizontal hand-shake is corrected, in a same way as that in the second embodiment (steps S22 to S31).

[0062]

However, the present embodiment is different from the second embodiment in that the j-th line is selected as a line for reading out data (step S29 in Fig. 5) in the second embodiment, while the q-th line is selected (step S37 in Fig. 6) in the present embodiment. By changing the vertical readout line according to the vertical correction data b, as described above, the image distortions caused by the vertical hand-shake can be corrected.

[0063]

Thereafter, the vertical line counter j is incremented one by one (step S32), and the processes at the steps S35 to S32 are repeated for all the effective vertical lines (step S33).

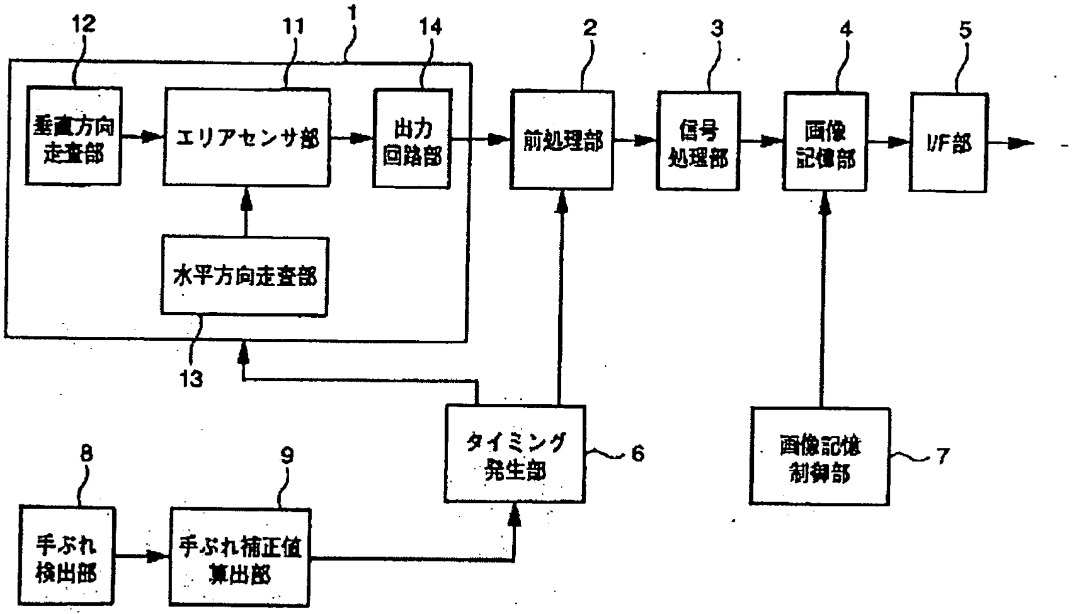
[0064]

As described above, the image storage control portion 27 controls to change the vertical-line readout position and the horizontal-pixel readout position from the image storage portion 4, on the basis of the output from the hand-shake correction value calculating portion 9. This enables correcting the image distortions caused by the vertical and horizontal hand-shakes.

[0065]

Also, it is possible to correct the image distortions caused by horizontal hand-shake, according to the same method as that of the first embodiment.

FIG. 1



1
12
11
14
2
3
4
5
垂直方向走査部
エリアセンサ部
出力回路部
前処理部
信号処理部
画像記憶部
I/F部
水平方向走査部
13
タイミング発生部
6
画像記憶制御部
7
8
9
手ぶれ検出部
手ぶれ補正値算出部

2) PRE-PROCESSING PORTION
3) SIGNAL PROCESSING PORTION
4) IMAGE STORAGE PORTION
5) I/F PORTION
6) TIMING GENERATING PORTION
7) IMAGE STORAGE CONTROL PORTION
8) HAND-SHAKE DETECTING PORTION
9) HAND-SHAKE CORRECTION VALUE CALCULATING PORTION
11) AREA SENSOR PORTION
12) VERTICAL SCANNING PORTION
13) HORIZONTAL SCANNING PORTION
14) OUTPUT CIRCUIT PORTION

FIG. 2

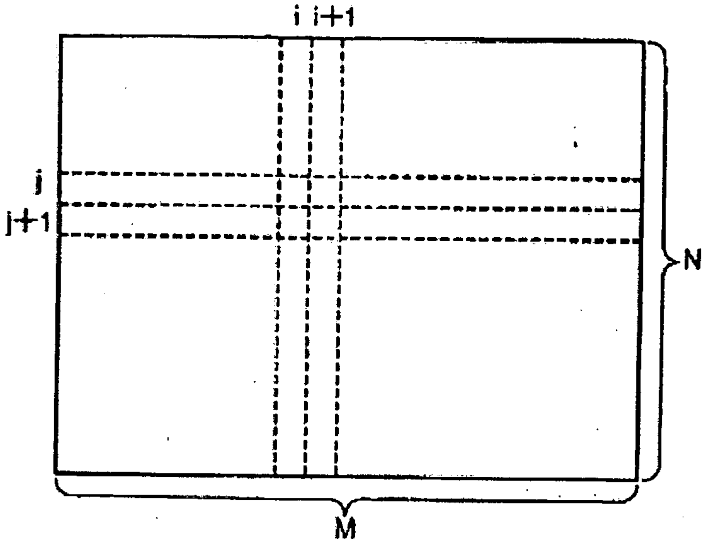
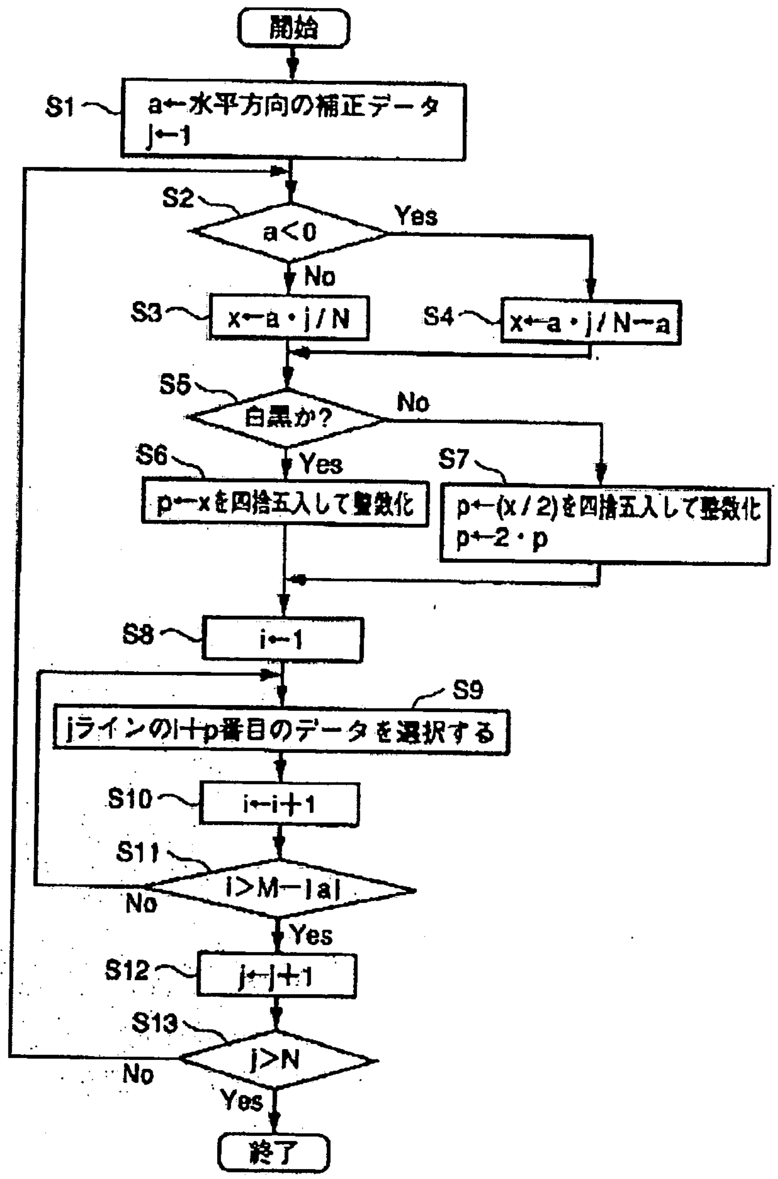


FIG. 3


開始
S1
a←水平方向の補正データ
j←1
S2
a<0
Yes
No
S3
x←a・j/N
S4
x←a・j/N−a
S5
白黒か?
No
S6
Yes
S7
p←xを四捨五入して整数化
p←(x/2)を四捨五入して整数化
p←2・p
S8
i←1
S9
jラインのi+p番目のデータを選択する
S10
i←i+1
S11
i>M−|a|
No
Yes
S12
j←j+1
S13
j>N
No
Yes
終了

START

S1) a←HORIZONTAL CORRECTION DATA

j←1

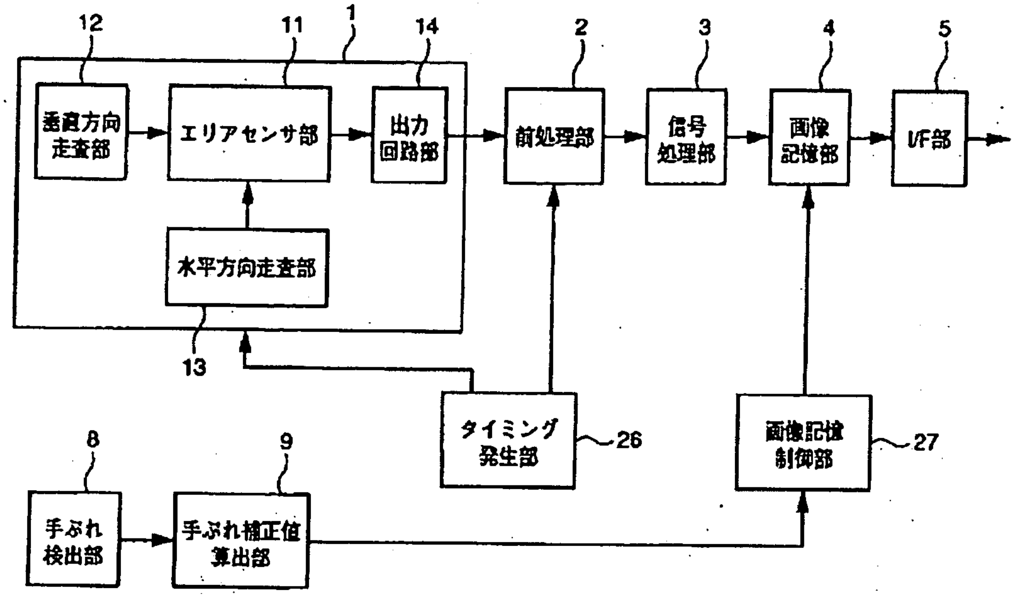
S5) MONOCHROME ?

S6) p←x; x HAS BEEN ROUNDED-OFF TO AN INTEGER VALUE

S7) p←(x/2); (x/2) HAS BEEN ROUNDED-OFF TO AN INTEGER

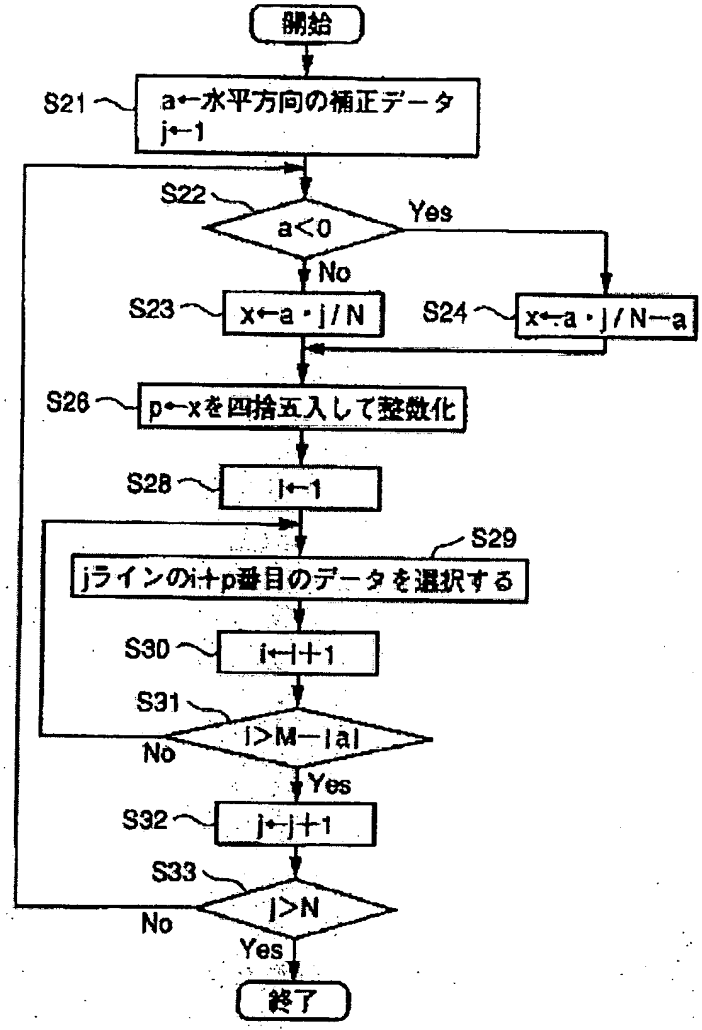
```
VALUE
       p←2*p
S9)    SELECT (i+p)-TH DATA ON j-TH LINE
       END
```

FIG. 4


12
11
1
14
2
3
4
5
垂直方向走査部
エリアセンサ部
出力回路部
前処理部
信号処理部
画像記憶部
I/F部
水平方向走査部
13
タイミング発生部
26
画像記憶制御部
27
8
9
手ぶれ検出部
手ぶれ補正値算出部

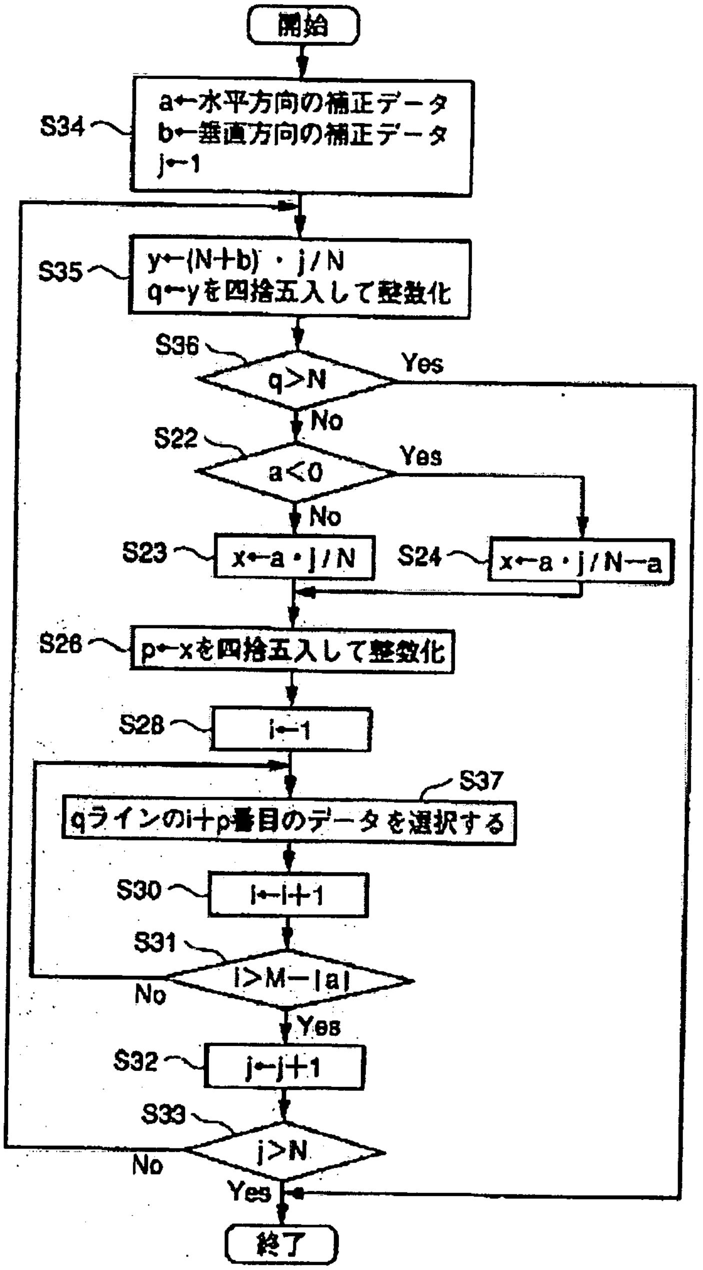
2) PRE-PROCESSING PORTION
3) SIGNAL PROCESSING PORTION
4) IMAGE STORAGE PORTION
5) I/F PORTION
8) HAND-SHAKE DETECTING PORTION
9) HAND-SHAKE CORRECTION VALUE CALCULATING PORTION
11) AREA SENSOR PORTION
12) VERTICAL SCANNING PORTION
13) HORIZONTAL SCANNING PORTION
14) OUTPUT CIRCUIT PORTION
26) TIMING GENERATING PORTION
27) IMAGE STORAGE CONTROL PORTION

FIG. 5


開始
S21
a←水平方向の補正データ
j←1
S22
a<0
Yes
No
S23
x←a・j/N
S24
x←a・j/N−a
S26
p←xを四捨五入して整数化
S28
i←1
S29
jラインのi+p番目のデータを選択する
S30
i←i+1
S31
i>M−|a|
No
Yes
S32
j←j+1
S33
j>N
No
Yes
終了

START
S21) a←HORIZONTAL CORRECTION DATA
j←1
S26) p←x; x HAS BEEN ROUNDED-OFF TO AN INTEGER VALUE
S29) SELECT (i+p)-TH DATA ON j-TH LINE
END

FIG. 6


開始
S34
a←水平方向の補正データ
b←垂直方向の補正データ
j←1
S35
y←(N+b)・j/N
q←yを四捨五入して整数化
S36
q>N
Yes
No
S22
a<0
Yes
No
S23
x←a・j/N
S24
x←a・j/N−a
S26
p←xを四捨五入して整数化
S28
i←1
S37
qラインのi+p番目のデータを選択する
S30
i←i+1
S31
i>M−|a|
No
Yes
S32
j←j+1
S33
j>N
No
Yes
終了

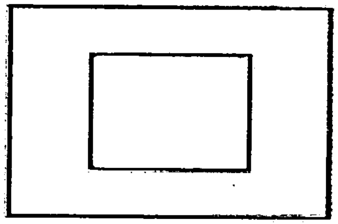
START

S34) a←HORIZONTAL CORRECTION DATA
b←VERTICAL CORRECTION DATA
j←1

S35) y←(N+b)*j/N

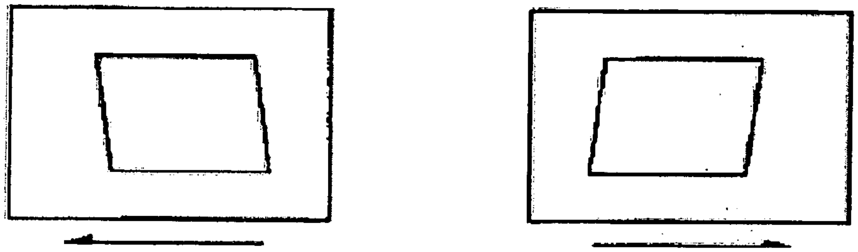
```
     p←y; y HAS BEEN ROUNDED-OFF TO AN INTEGER VALUE
S26) p←x; x HAS BEEN ROUNDED-OFF TO AN INTEGER VALUE
S37) SELECT (i+p)-TH DATA ON q-TH LINE
     END
```

FIG. 7



AT REST

(a)

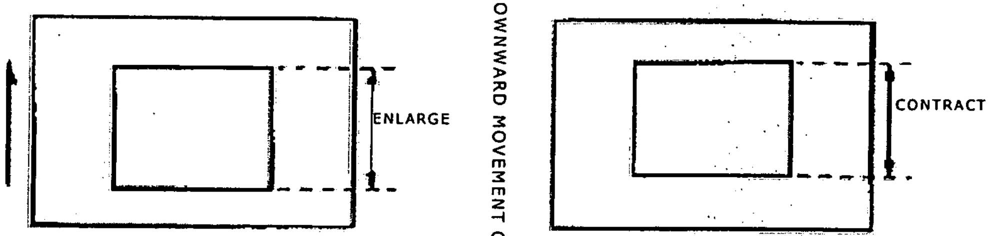


WHEN LEFTWARD MOVEMENT OCCURS

(b)

VHEN RIGHTWARD MOVEMENT OCCUR!

(c)


ENLARGE
CONTRACT

WHEN UPWARD MOVEMENT OCCURS

(d)

WHEN DOWNWARD MOVEMENT OCCURS

(e)